

## DESCRIPTION

LINE CONVERTER, HIGH-FREQUENCY MODULE, AND COMMUNICATION  
DEVICE

## 5 Technical Field

The present invention relates to a line converter for a transmission line used for at least one of a microwave band and a millimeter-wave band, a high-frequency module including the line converter, and a communication device.

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## Background Art

In the past, line converters for performing line conversion between a plane circuit formed by using a dielectric substrate and a three-dimensional waveguide for propagating an electromagnetic wave in a three-dimensional space have been disclosed in Patent Document 1 (Japanese Unexamined Patent Application Publication No. 60-192401) and Patent Document 2 (Japanese Unexamined Patent Application Publication No. 2001-111310).

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In the line converter according to Patent Document 1, an end of a micro-strip line formed as part of the plane circuit is inserted in a terminal short-circuit waveguide tube divided into two parts by a plane E of the waveguide tube. The two parts of the terminal short-circuit waveguide tube penetrate a groove formed in the dielectric substrate

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and sandwich the dielectric substrate therebetween.

In the line converter according to Patent Document 2, the dielectric substrate is provided at a position that is away from a short-circuit plane of a terminal short-circuit  
5 waveguide tube by as much as a predetermined distance and in a predetermined direction orthogonal to the electromagnetic-wave propagation direction.

In the case of the line converter of Patent Document 1, there is a need to form a penetrating groove in the  
10 dielectric substrate, so as to penetrate part of the waveguide tube divided into two parts. Therefore, where the dielectric substrate is formed as a ceramic substrate including aluminum or the like, it becomes difficult to machine the dielectric substrate. Further, coupling of the  
15 micro-strip line is achieved at a position where the intensity of electric fields generated by a standing wave generated at a terminal end of the waveguide is high. The coupling characteristic is determined by the positional relationship between the dielectric substrate including the  
20 micro-strip line and the waveguide tube. Therefore, the coupling characteristic is affected by the precision of assembling the dielectric substrate and the waveguide tube, which makes it difficult to obtain a line-conversion characteristic according to predetermined design without  
25 variations.

In the line converter according to Patent Document 2,  
the dielectric substrate is provided in a predetermined  
direction orthogonal to the electromagnetic-wave propagation  
direction of the waveguide tube. Therefore, the positional  
5 relationship between the three-dimensional waveguide formed  
by the waveguide tube and the plane circuit formed by the  
dielectric substrate is determined with a low degree of  
flexibility. Subsequently, the plane circuit cannot be  
provided in a predetermined direction parallel to the  
10 electromagnetic-wave propagation direction of the waveguide  
tube.

An object of the present invention is to provide a line  
converter wherein a plane circuit can be provided in a  
predetermined direction parallel to the direction in which  
15 an electromagnetic wave propagates through a three-  
dimensional waveguide, a dielectric substrate can be easily  
machined, and the characteristic of coupling between the  
plane circuit formed on the dielectric substrate and the  
three-dimensional waveguide is prevented from being affected  
20 by the precision of assembling the plane circuit and the  
three-dimensional waveguide so that a line-conversion  
characteristic according to predetermined design can be  
easily obtained, a high-frequency module including the line  
converter, and a communication device.

#### Disclosure of Invention

For achieving the above-described object, the present invention provides:

a line converter including a three-dimensional  
5 waveguide for propagating an electromagnetic wave in a three-dimensional space and a plane circuit having a predetermined conductor pattern formed on a dielectric substrate, so as to perform line conversion between the plane circuit and the three-dimensional waveguide.

10 The line converter is characterized in that the dielectric substrate is provided, so as to be parallel to a plane E of the three-dimensional waveguide and at a nearly center part of the three-dimensional waveguide, and

the conductor pattern of the dielectric substrate  
15 includes a conductor part forming a shield area of the three-dimensional waveguide, a coupling-line part that is electromagnetically coupled to a standing wave that occurs in the shield area, and a transmission-line part continuing from the coupling-line part.

20 Thus, a standing wave required for electromagnetically coupling the three-dimensional waveguide to the transmission line on the plane circuit is generated by the shield area formed by the conductor part provided on the dielectric substrate. Therefore, the positional-relationship between  
25 the conductor part on the dielectric-substrate side forming

the shield area of the three-dimensional waveguide and the coupling-line part that is electromagnetically-coupled to the standing wave generated at the shield area is determined only by the precision of forming the conductor pattern on  
5 the dielectric substrate. Subsequently, a stable coupling characteristic can be obtained without being affected by the precision of assembling the three-dimensional waveguide and the plane circuit, and a line-conversion characteristic according to predetermined design can be obtained.

10 Further, the present invention is characterized in that the conductor part forming the shield area is formed, as ground conductors formed on both faces of the dielectric substrate.

Further, the present invention is characterized by  
15 having a plurality of conduction paths that penetrates the dielectric substrate and that is aligned on at least one of both sides, so as to be away from the transmission line by as much as a predetermined distance, so that conduction is established between the ground conductors formed on the both  
20 faces of the dielectric substrate.

Further, the present invention is characterized in that a conductor of the three-dimensional waveguide is divided into two parts including an upper part and a lower part by a plane parallel to the plane E and a space is provided in the  
25 conductor of the three-dimensional waveguide, so as to

create a choke by the space, where the space is provided at a position away from the three-dimensional waveguide by as much as a predetermined distance, so as to be parallel to an electromagnetic-wave propagation direction of the three-dimensional waveguide.

Further, the present invention is characterized by including the line converter and a high-frequency circuit connected to each of the plane circuit and the three-dimensional waveguide of the line converter.

Further, the present invention is characterized by forming a communication device including the high-frequency module in a unit for transmitting and receiving an electromagnetic wave.

#### Brief Description of the Drawings

Fig. 1 shows sectional views and a plan view of a line converter according to a first embodiment of the present invention.

Fig. 2 shows exploded plan views illustrating the line converter.

Fig. 3 is a sectional view showing an example electric-field intensity distribution of a three-dimensional waveguide illustrating the result of three-dimensional electromagnetic-field analysis simulation for the line converter.

Fig. 4 is a plan view showing the result of three-dimensional electromagnetic-field analysis simulation for the line converter.

Fig. 5 is another plan view showing the result of three-dimensional electromagnetic-field analysis simulation for the line converter.

Fig. 6 illustrates a line converter according to a second embodiment of the present invention.

Fig. 7 shows exploded plan views of the line converter.

Fig. 8 is a block diagram illustrating a high-frequency module according to a third embodiment of the present invention.

Fig. 9 is a block diagram illustrating a communication device according to a fourth embodiment of the present invention.

#### Best Mode for Carrying Out the Invention

The configuration of a line converter according to a first embodiment of the present invention will now be described with reference to Figs. 1 to 5.

Fig. 1 shows the configuration of the line converter. Fig. 1(C) is a plan view showing the line converter after an upper conductor plate 2 and an upper dielectric strip 7 are removed therefrom. Fig. 1(A) is an A-A' sectional view of the line converter shown in Fig. 1(C), where the upper

conductor plate 2 is mounted thereon. Fig. 1(B) is a B-B' sectional view of the line converter shown in Fig. 1(C), where the upper conductor plate 2 is mounted thereon, as in the case of Fig. 1(A).

5        Here, reference numeral 1 denotes a lower conductor plate, reference numeral 2 denotes the upper conductor plate, reference numeral 3 denotes a dielectric substrate, and reference numerals 6 and 7 denote dielectric strips. The dielectric substrate 3 is provided, so as to be sandwiched  
10 between the lower conductor plate 1 and the upper conductor plate 2, and the dielectric strips 6 and 7.

Fig. 2 shows exploded plan views illustrating the configuration of each part of the line converter shown in Fig. 1. Fig. 2(A) shows the top surface of the upper  
15 conductor plate 2, Fig. 2(B) shows the top surface of the dielectric substrate 3, Fig. 2(C) shows a conductor pattern on the undersurface of the dielectric substrate 3, and Fig. 2(D) is a plan view of the lower conductor plate 1.

A three-dimensional-waveguide groove G11 is provided on  
20 the lower conductor plate 1 and a three-dimensional-waveguide groove G21 is provided on the upper conductor plate 2. The lower dielectric strip 6 is inserted in the three-dimensional-waveguide groove G11. The upper dielectric strip 7 is inserted in the three-dimensional-  
25 waveguide groove G21. By overlaying the two conductor



plates 1 and 2 one another, the two dielectric strips 6 and 7 are opposed to each other. Subsequently, a dielectric-filled waveguide (DFWG) (hereinafter simply referred to as a "waveguide") is formed.

5        A predetermined plane of the waveguide is determined to be a plane E (a conductor plane parallel to the electric field of a TE<sub>10</sub> mode that is the mode of a propagating electromagnetic wave), where the plane E is parallel to the lower conductor plate 1 and the upper conductor plate 2.

10      Therefore, the dielectric substrate 3 is provided at a position parallel to the plane E of the waveguide and corresponding to the nearly center part of the waveguide (part between the lower conductor plate 1 and the upper conductor plate 2).

15        The conductor plates 1 and 2 are formed by machining a metal plate including aluminum or the like, for example. Further, the dielectric strips 6 and 7 are formed by injection-molding or machining a fluoroplastic resin. The dielectric substrate 3 is formed by using a ceramic  
20      substrate including aluminum or the like.

      A transmission-line conductor 4a and a coupling-line conductor 4k continuing therefrom are formed on the undersurface of the dielectric substrate 3 (the side facing the lower conductor plate 1). A ground conductor 5g is  
25      formed on the top surface of the dielectric substrate 3 (the

side facing the upper conductor plate 2). The transmission-line conductor 4a formed on the dielectric substrate 3 and the ground conductor 5g formed on the surface facing the transmission-line conductor 4a form a micro-strip line.

5 A notch part is formed on the ground conductor 5g on the top surface of the dielectric substrate 3, as indicated by reference character N shown in Fig. 2(B). The coupling-line conductor 4k facing the notch part N, the dielectric substrate 3, the lower conductor plate 1, and the upper  
10 conductor plate 2 form a suspended line. The transmission-line conductor 4a and the coupling-line conductor 4k are formed on the undersurface-side of the dielectric substrate 3 and the ground conductor 4g is formed in a predetermined area away from the transmission lines by as much as a  
15 predetermined distance.

As shown in Fig. 2(D), the lower conductor plate 1 has a transmission-line groove G12 that is formed thereon and along the transmission line 4a. The transmission-line groove G12 provides a predetermined space on the hotline  
20 side of the above-described micro-strip line and functions as a shield.

Further, a plurality of conduction paths (via holes) V for achieving continuity between the ground conductors 4g and 5g on the top surface and the undersurface of the  
25 dielectric substrate 3 is aligned on both sides of the

transmission-line conductor 4a and the coupling-line conductor 4k, so as to be away therefrom by as much as a predetermined distance. Subsequently, unnecessary coupling between spurious mode such as parallel-flat-plate mode  
5. generated between parallel flat plates, that is, the upper and lower ground conductors 4g and 5g sandwiching the dielectric substrate 3 therebetween and micro-strip-line mode generated by the transmission-line conductor 4a and the ground conductor 5g is shielded. Further, unnecessary  
10 coupling between suspended-line mode generated by the coupling-line conductor 4k, the dielectric substrate 3, and the conductor plates 1 and 2 and the above-described spurious mode is shielded. Further, the conduction paths (via holes) V may be aligned on one side of the  
15 transmission-line conductor 4a and the coupling-line conductor 4k, so as to be away therefrom by as much as a predetermined distance.

For sandwiching the dielectric substrate 3 having various conductor patterns formed thereon between the two  
20 conductor plates 1 and 2 in the above-described manner, the dielectric substrate 3 is provided at a predetermined position with reference to the conductor plates 1 and 2 so that the coupling-line conductor 4k is inserted in the waveguide in a predetermined direction orthogonal to the  
25 electromagnetic-propagation direction of the waveguide. The

ground conductors 4g and 5g are formed on the dielectric substrate 3 so that part of each of the ground conductors 4g and 5g is inserted in the waveguide. As shown in Fig. 1, part of the ground conductors 4g and 5g is designated by reference character S. This part forms a shield area of the waveguide. That is to say, by forming a ground conductor parallel to the plane E at the nearly center part of the waveguide, the waveguide is divided by the plane parallel to the plane E, whereby the shield wavelength of the waveguide is reduced and the shield area is formed in the waveguide. Specifically, the part designated by reference character S functions as a conductor part forming the shield area relating to the present invention.

As shown in Fig. 2(A), the upper conductor plate 2 has a choke groove G22 that is parallel to the electromagnetic wave propagation direction of the waveguide and that is away from the waveguide (from the three-dimensional-waveguide groove G21) by as much as a predetermined distance. Therefore, where the conductor plate 1 is placed on the upper conductor plate 2, a clearance generated at the interface forms a discontinuity part. However, an electromagnetic wave that is likely to leak from the clearance is released in the space of the choke groove G22. Where the distance between a part indicated by reference characters Co and a part indicated by reference characters

Cs corresponds to substantially one-fourth of a propagation wavelength in Fig. 1(B), the part Co functions as an open end. Subsequently, the part Cs equivalently functions, as a short-circuit end. Therefore, the radiation loss generated from the clearance created by the two conductor plates 1 and 2 placed on one another hardly occurs.

The positional relationship between the conductor part S forming the above-described shield area and the coupling-line conductor 4k depends on the dimension precision of the conductor pattern with reference to the dielectric substrate 3. The forming precision of the conductor pattern with reference to the dielectric substrate is significantly higher than the assembly precision of the dielectric substrate 3 with reference to the conductors 1 and 2. Therefore, the relative position of a standing wave of the three-dimensional waveguide, where the standing wave occurs by the shield area, with respect to the coupling-line conductor 4k is maintained according to predetermined design at all times. Subsequently, the characteristic of line-conversion between the waveguide and the plane circuit can be obtained according to predetermined design at all time.

Next, the result of simulation performed for an example design will now be described according to Figs. 3 to 5. The design circumstances are as follows.

Frequency: 76-GHz band

Width of the three-dimensional waveguide grooves G11  
and G21:  $W_g = 1.2 \text{ mm}$

Depth of the three-dimensional waveguide grooves G11  
and G21:  $H_g = 0.9 \text{ mm}$

5 Dielectric constant of the dielectric strips 6 and 7:

2

Width of the dielectric strips 6 and 7:  $W_d = 1.1 \text{ mm}$

Height of the dielectric strips 6 and 7:  $H_d = 0.9 \text{ mm}$

Dielectric constant of the dielectric substrate 3: 10

10 Thickness of the dielectric substrate 3:  $t = 0.2 \text{ mm}$

Line width of the transmission-line conductor 4a and  
the coupling-line conductor 4k:  $W_c = 0.2 \text{ mm}$

Fig. 3 shows the result of three-dimensional  
electromagnetic-field analysis simulation illustrating line  
15 conversion between the waveguide and the plane circuit.  
Further, Fig. 4 shows a cross-sectional view of the  
waveguide part. In Fig. 3, white and periodically shown  
patterns indicate the electric-field intensity distribution.  
In Fig. 4, ring-like patterns indicate the electric-field-  
20 intensity distribution. When comparing Figs. 3, 4, 1(A),  
and 1(C) to one another, it is clear that the standing wave  
is generated by the waveguide-shield area formed by the  
conductor part S and electromagnetically coupled to the  
suspended line formed by the coupled-connection conductor 4k  
25 at a position where the electric-field intensity of the

standing wave increases to a maximum value. That is to say, a distance  $L_d$  between the conductor part S forming the shield area and the coupling-line conductor 4k is determined so that the coupling-line conductor 4k is provided at a  
5 predetermined position where the electric-field distribution of the standing wave shows a maximum value.

The generation of the above-described standing wave is affected by the positions of ends of the dielectric strips 6 and 7. Therefore, the distance between the ends of the  
10 dielectric strips 6 and 7, and the coupling-line conductor 4k is determined so that the coupling-line conductor 4k is provided at a position where the electric-field-intensity distribution of the standing wave shows the maximum value. However, variations in the distance between the ends of the  
15 dielectric strips 6 and 7, and the coupling-line conductor 4k exert a relatively small influence on the standing-wave generation. Therefore, the assembly precision of the dielectric strips 6 and 7, and the dielectric substrate 3 with reference to the conductor plates 1 and 2 may be low.

20 The mode of the above-described suspended line is converted to the mode of the micro-strip line formed by the transmission-line conductor 4a so that electromagnetic waves are propagated in order.

Fig. 5 shows the result of reflection characteristic  
25  $S_{11}$  in the line-conversion part. As shown in this drawing,

a low-reflection characteristic of under -40 dB is obtained in a 76-GHz band. Subsequently, it becomes possible to provide a line converter showing high line-conversion efficiency.

5       Next, a line converter according to a second embodiment of the present invention will be described with reference to Figs. 6 and 7.

      The line converter according to the second embodiment performs line conversion between a hollow rectangular  
10    waveguide tube and a plane circuit. Fig. 6(C) is a plan view of the line converter after an upper conductor plate is removed therefrom. Fig. 6(A) is a right-side elevational view of the line converter, where the upper conductor plate is mounted thereon, and Fig. 6(B) is a sectional view of a  
15    B-B' portion of the line converter shown in Fig. 6(C), where the upper conductor plate is mounted on the line converter, as in the case of Fig. 6(A).

      Here, reference numeral 1 denotes a lower conductor plate, reference numeral 2 denotes the upper conductor plate,  
20    and reference numeral 3 denotes a dielectric substrate. The dielectric substrate 3 is provided, so as to be sandwiched between the lower conductor plate 1 and the upper conductor plate 2.

      Fig. 7 shows exploded plan views illustrating the  
25    configuration of each part of the line converter. Fig. 7(A)



shows the top surface of the upper conductor plate 2, Fig. 7(B) shows the top surface of the dielectric substrate 3, Fig. 7(C) shows a conductor pattern on the undersurface side of the dielectric substrate 3, and Fig. 7(D) is a plan view of the lower conductor plate 1.

A three-dimensional-waveguide groove G11 is provided on the lower conductor plate 1 and a three-dimensional-waveguide groove G21 is provided on the upper conductor plate 2. By overlaying the two conductor plates 1 and 2 one another, the two three-dimensional-waveguide grooves are opposed to each other. Subsequently, the hollow rectangular waveguide tube (hereinafter simply referred to as a "waveguide tube") is formed.

Unlike the first embodiment, the waveguide tube has a pass-through configuration in predetermined areas shown in Figs. 6 and 7 so that no dielectric material is filled therein.

A predetermined plane of the waveguide tube is determined to be a plane E (a conductor plane parallel to the electric field of a TE<sub>10</sub> mode that is the mode of a propagating electromagnetic wave), where the plane E is parallel to the lower conductor plate 1 and the upper conductor plate 2. Therefore, the dielectric substrate 3 is provided at a position that is parallel to the plane E of the waveguide tube and that corresponds to the nearly center

part of the waveguide tube (a part between the lower conductor plate 1 and the upper conductor plate 2).

A transmission-line conductor 4a and a coupling-line conductor 4k continuing therefrom are formed on the undersurface of the dielectric substrate 3 (the side facing the lower conductor plate 1). A ground conductor 5g is formed on the top surface of the dielectric substrate 3 (the side facing the upper conductor plate 2). The transmission-line conductor 4a formed on the dielectric substrate 3 and the ground conductor 5g formed on the plane facing the transmission-line conductor 4a form a micro-strip line. In this embodiment, the ground conductor 5g is formed only on the top-surface side of the dielectric substrate 3.

A notch part is formed on the ground conductor 5g, as indicated by reference character N shown in Fig. 2(B). The coupling-line conductor 4k facing the notch part N, the dielectric substrate 3, the lower conductor plate 1, and the upper conductor plate 2 form a suspended line.

Where the dielectric substrate 3 is sandwiched between the two conductor plates 1 and 2, as is the case with the first embodiment, the dielectric substrate 3 is provided at a predetermined position with reference to the conductor plates 1 and 2 so that the coupling-line conductor 4k is inserted in the waveguide in a predetermined direction orthogonal to the electromagnetic-wave-propagation direction

of the waveguide tube. At the same time, the dielectric substrate 3 is provided at a predetermined position so that the ground conductor 5g is inserted in the nearly center part of the waveguide tube, so as to be parallel to the plane E. A waveguide-shield area of the waveguide is formed by predetermined part designated by reference character S shown in Fig. 6 of the ground conductor 5g. The part indicated by reference character S is a conductor part forming the shield area.

According to the above-described configuration, line conversion between the hollow waveguide tube and the plane circuit can be achieved.

Further, according to the first and second embodiments, the coupling-line conductor, the transmission-line conductor, and the ground conductors are formed on the surfaces of the dielectric substrate 3. However, part of or all the conductors may be formed inside the dielectric substrate (internal layers).

Further, the dielectric-filled waveguide is used in the first embodiment, as the three-dimensional waveguide, and the hollow waveguide tube is used in the second embodiment, as the three-dimensional waveguide. However, a dielectric line including a dielectric strip sandwiched between parallel conductor planes may be formed. Particularly, a non-radiative dielectric line may be formed.

Next, the configuration of a high-frequency module according to a third embodiment will be described with reference to Fig. 8.

Fig. 8 is a block diagram showing the configuration of the high-frequency module.

In Fig. 8, reference characters ANT denote a transmission/reception antenna, reference characters Cir denote a circulator, each of reference characters BPFa and BPFb denotes a band-pass filter, each of reference characters AMPa and AMPb denotes an amplifier circuit, each of reference characters MIXa and MIXb denotes a mixer, reference characters OSC denote an oscillator, reference characters SYN denote a synthesizer, and reference characters IF denote an intermediate-frequency signal.

The MIXa mixes an input IF signal and a signal output from the SYN, the BPFa makes only a predetermined signal of the mixed output signals transmitted from the MIXa pass, where the predetermined signal corresponds to a transmission-frequency band. The AMPa amplifies the electrical power of the signal and transmits the signal from the ANT via the Cir. The AMPb amplifies reception signals taken from the Cir. The BPFb makes only a predetermined signal of the reception signals transmitted from the AMPb pass, where the predetermined signal corresponds to a reception-frequency band. The MIXb mixes a frequency signal

transmitted from the SYN and the reception signal, and outputs an intermediate-frequency signal IF.

A predetermined high-frequency component including the line converter according to the first embodiment, or the second embodiment can be used, as the amplifier circuits AMPa and AMPb shown in Fig. 8. That is to say, the dielectric-filled waveguide or the hollow waveguide is used, as the transmission line, and the plane circuit including an amplifier circuit provided on the dielectric substrate is used. By using the high-frequency component including the amplifier circuits and the line converter, a high-frequency module with a low loss and good communication performance is obtained.

Next, the configuration of a communication device according to a fourth embodiment of the present invention will be described with reference to Fig. 9.

Fig. 9 is a block diagram showing the configuration of the communication device according to the fourth embodiment. The communication device includes the high-frequency module shown in Fig. 8 and a predetermined signal-processing circuit. The signal-processing circuit shown in Fig. 9 includes an encoding-and-decoding circuit, a synchronization-control circuit, a modulator, a demodulator, a CPU, and so forth, and further includes a circuit for inputting and outputting transmission and reception signals

to and from the signal-processing circuit. Thus, the communication device including the high-frequency module is formed, where the high-frequency module is used, as a unit for transmitting and receiving an electromagnetic wave.

5        Thus, by using the above-described line converter for performing line conversion between the three-dimensional waveguide and the plane circuit, and the high-frequency module using the line converter, a communication device with a low loss and good communication performance is formed.

10        As has been described, the present invention allows forming a shield area of a three-dimensional waveguide by using a conductor pattern of a dielectric substrate. Therefore, the positional relationship between a conductor part on the dielectric-substrate side, where the conductor  
15        part forms the shield area of the three-dimensional waveguide, and a coupling-line part electromagnetically-coupled to a standing wave generated in the shield area can be determined only by the precision of forming the conductor pattern with reference to the dielectric substrate.

20        Subsequently, it becomes possible to obtain a stable coupling characteristic and a line-conversion characteristic according to predetermined design, without being affected by the precision of assembling the three-dimensional waveguide and the plane circuit.

25        Further, according to the present invention, the

conductor part creating the shield area is formed, as ground  
conductors formed on both faces of the dielectric substrate.  
Therefore, the shielding effect of the three-dimensional  
waveguide increases and the size of the line converter  
5 decreases.

Further, according to the present invention, conduction  
is established between the ground conductors by using  
conduction paths. The conduction paths are formed on at  
least one of both sides of the transmission line, so as to  
10 be away from the transmission line by as much as a  
predetermined distance and on both the faces of the  
dielectric substrate, so as to be provided along the  
transmission line. Subsequently, the coupling line and the  
transmission line are hardly coupled with spurious mode, so  
15 that a good spurious characteristic can be obtained.

Further, according to the present invention, a space is  
provided in the conductor of the three-dimensional waveguide,  
so as to form a choke, where the space is provided at a  
predetermined distance from the three-dimensional waveguide,  
20 so as to be parallel to the electromagnetic-wave propagation  
direction of the three-dimensional waveguide. Subsequently,  
where the two conductor plates are joined together and the  
three-dimensional waveguide is formed, the radiated  
electrical-power loss of the three-dimensional waveguide  
25 decreases.

Further, the present invention provides a low-loss high-frequency module including a line converter and a high-frequency circuit connected to a plane circuit and a three-dimensional waveguide of the line converter.

5 Further, the present invention provides a communication device with decreased losses caused by line conversion and a suitable communication characteristic.

#### Industrial Applicability

10 As has been described, according to the line converter of the present invention, the characteristic of coupling between the plane circuit and the three-dimensional waveguide that are formed on the dielectric substrate is not affected by the precision of assembling the plane circuit  
15 and the three-dimensional waveguide so that a line-conversion characteristic according to predetermined design can be easily obtained. Therefore, the line converter can be used for a high-frequency module and a communication device used for at least one of a microwave band and a  
20 millimeter-wave band, for example.